Temporal Behaviour of the Anthropogenic Metabolism of selected Brominated Flame Retardants: Emissions to the Environment

Andreas M. Buser[1], Leo S. Morf[1], Ruedi Taverna[1], Hans Peter Bader[2], Ruth Scheidegger[2]

[1]GEO Partner AG Environmental Management, Baumackerstrasse 24, 8050 Zurich, Switzerland
[2]Swiss Federal Institute of Aquatic Science and Technology, Überlandstrasse 133, 8600 Dübendorf, Switzerland

Introduction

Most studies on potentially hazardous substances are focused on aspects about their occurrence and fate in the environment (monitoring and modelling studies). This information is useful to estimate the environment impact and the potential exposure of human. In order to early recognize future environmental impacts, it is essential to know their anthropogenic metabolism, too. A better knowledge of the quantities of the flows, stocks and emissions from the use and waste management processes and their temporal behaviour is essential for effective risk reduction measures and effective chemical management, particularly during the disposal and reuse phases. To get an overview about sources and final sinks for selected brominated flame retardants (BFR) a dynamic substance flow analysis (SFA) has been elaborated for Switzerland. In combination with outcomes of other studies (e.g. Anonymous 1999; Morf et al. 2005), the results will serve as a base for recommendations for future regulatory and technical measures regarding the use and disposal of the selected BFR.

Materials and Methods

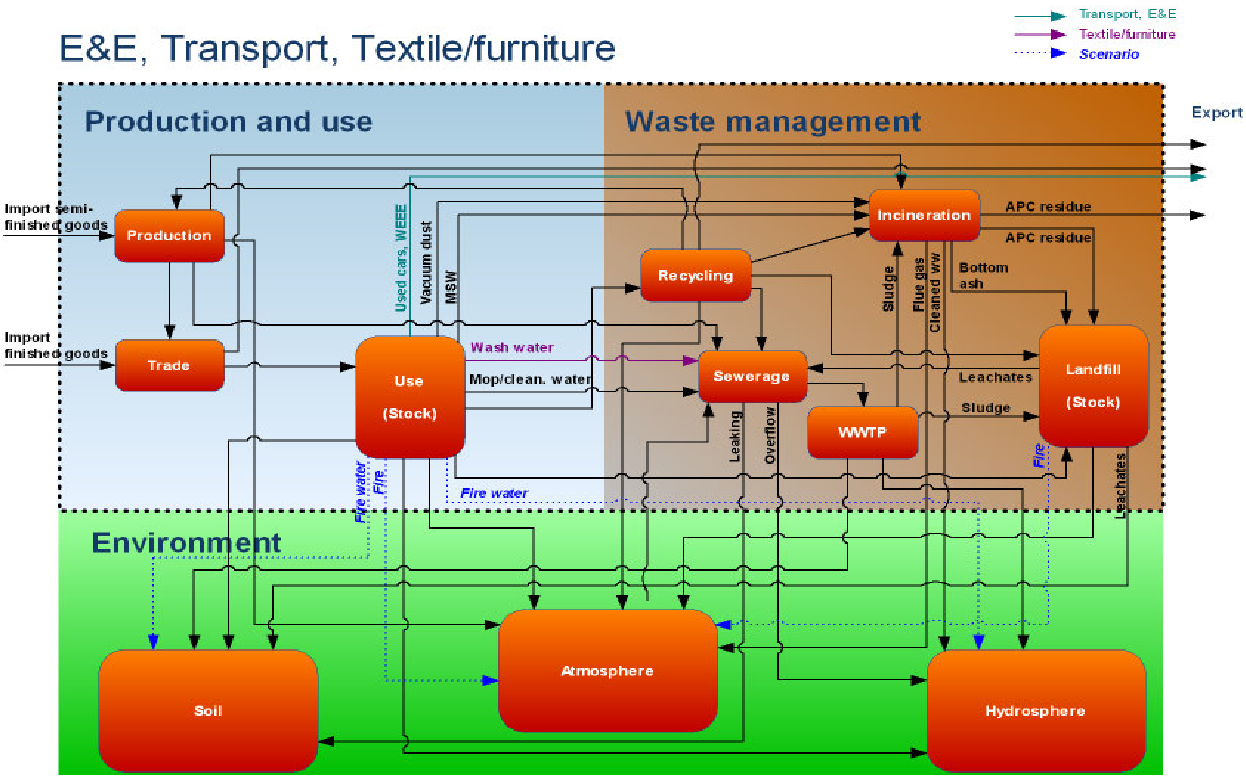

Figure 1 System for the application areas E&E, transport and textile

In order to investigate the dynamic behaviour of the anthropogenic metabolism and estimate temporal trends of emissions from technosphere to the environment, a dynamic substance flow analysis model has been established and required input data for the SFA model have been determined. The spatial system boundary was the political border of Switzerland and the temporal period 1980-2020. The substances selected were HBCD, DecaBDE, PentaBDE, OctaBDE and TBBPA. The data (e.g. transfer coefficients, emission factors) was gathered from own studies (Morf et al. 2003; Morf et al. 2005) and by reviewing the literature published and in collaboration with researchers from Empa – Materials Science & Technology as well as Swiss Federal Institute of Aquatic Science and Technology and contacts to many research groups, organisations, authorities and industry from all over the world have been established. The method consisted of the determination of the flows and stocks of the selected substances in subordinate systems and application areas and the following aggregation to form the whole system. Figure 1 illustrates the system established for the application areas E&E, transport and textile/furniture. The system for the construction application area does allow investigating in slightly more detail the "Use"- process.

Results and Discussion

Figure 2 shows the estimated consumption trends for DecaBDE and HBCD in Switzerland based on two approaches: a bottom-up approach based on import and export statistics combined with data about product/material content and a top-down approach derived from industrial demand data regarding the selected BFRs (source: BSEF and CEFIC). The bottom-up consumption estimate is split up in the four application areas. As uncertainties of the individual factors used are multiplicative, the domains of uncertainty are estimated as 30% to 50%. The distribution in Europe is not known exactly. It is known that due to more stringent fire regulations, consumption in the UK is higher than average, while it is lower e.g. in Scandinavian countries. The per capita consumption in Switzerland was estimated as approximately intermediate. As for DecaBDE, imports of electronic equipment from Asia and America are important, the higher estimate than the per capita industrial demand is reasonable. The consumption trend in Japan showed is not comparable with Switzerland, as consumption has been decreasing since beginning of the 1990s due to an industry commitment (Tokai et al. 2004).

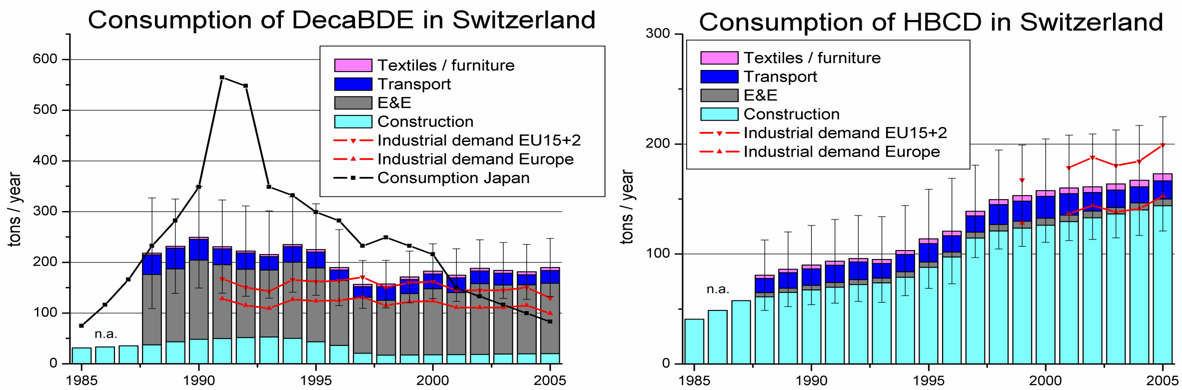

Figure 2 Estimated consumption trend of DecaBDE and HBCD in Switzerland using import and export figures; comparison to industrial demand data converted on a per capita base

In the scenario with no regulative restriction of DecaBDE or HBCD (see figures 3 and 4), the stock of HBCD in the process "Use" amounts to about 2,000 tons at present and is expected to double until 2020. EPS and XPS insulation panels make up by far the largest proportion of the stock. The amount of DecaBDE in the stock in "Use" is about the same at present, but it is supposed to be virtually stable in future. Here, electrical and electronic equipment is the most relevant application area. The amounts stored in waste management are one order of magnitude lower than in the use phase. In consequence of the technical ordinance on waste (Technische Verordnung über Abfälle, TVA) and the restrictions of disposal on landfills in Switzerland, the accumulated BFR mass in landfills is increasing much slower than before the mid-Nineties.

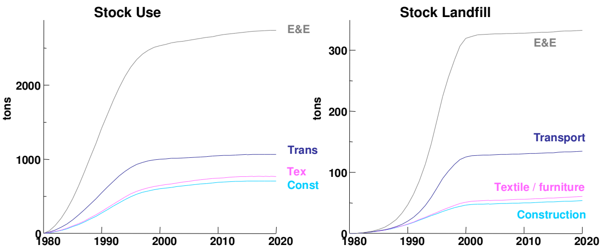

Figure 3 Trend of stocks of DecaBDE and in the processes "Use" and "Landfill" (cumulative graphics)

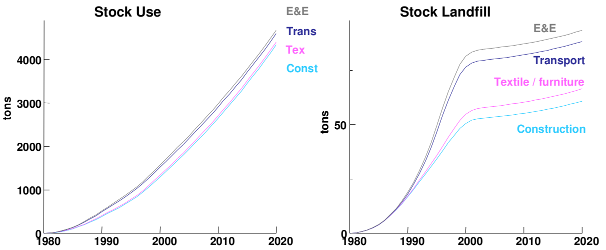

Figure 4 Trend of stocks of HBCD in the processes "Use" and "Landfill" (cumulative graphics)

As figure 5 indicates, there is an increase in emissions of DecaBDE until 1990, followed by a decrease until the late 2000s. The emissions are expected to stay virtually constant within the next decade, if no ban is assumed. Total emissions estimates at the end of the Nineties are more than one order of magnitude lower than estimated in Morf et al. (2003), as worst case assumptions had to be applied in that study. Emissions to atmosphere make up to 15 kg/year, emissions to hydrosphere up to 8 kg/year and emissions to soil up to 55 kg/year at maximum. Wastewater is the most relevant emission pathway into soil and hydrosphere, especially in the past. As the usage of sewage sludge as fertilizer in agriculture has been declining over time and was prohibited beginning October 1st 2006, the emissions to soil decreased significantly in Switzerland. The releases to sewerage from production processes are most relevant, while smaller amounts originate from the use phase, recycling and atmospheric deposition. On the other hand, releases from landfills to wastewater are negligible.

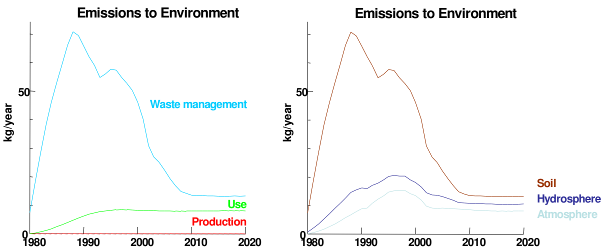

Figure 5 Emissions of DecaBDE to environment split up by source and environmental compartment (cumulative graphics)

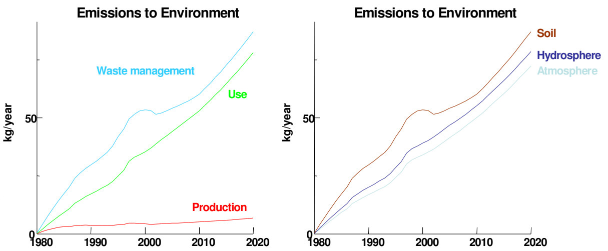

Figure 6 Emissions of HBCD to environment split up by source and environmental compartment (cumulative graphics)

As shown in figure 6, emissions of HBCD are in a similar range like DecaBDE, but in contrast to DecaBDE, the emissions of HBCD are increasing to date and are expected to continue increasing in future. The atmospheric emissions of insulation panels originating from the use phase including construction and deconstruction processes make up the largest proportion. These emissions would continue for many decades even in the case of a ban for this substance. Emissions to soil show a similar trend as for DecaBDE, but they are lower and peak significantly later.

For both, DecaBDE and HBCD, the flows from use to waste management are increasing over the whole period under study. This indicates the more important role of adequate waste management strategies in order to avoid emissions of these substances in the future. In the case of Switzerland, there is an almost linear increase for HBCD, while the increase of DecaBDE begins to flatten at the beginning of this century.

Due to limited and partly highly variable emission measurements (e.g. Klatt 2004; Sakai et al. 2006) and uncertainties in the substance flows, the domain of uncertainty is high for the emissions to the environment. The gradually increasing emissions of HBCD correspond well with concentrations trends found in sediment cores (Kohler et al. 2005; Kohler et al. 2006), while the decrease of DecaBDE in recent years modelled can not be explained with measurements in the environment (yet). Missing flows from the use or end of life phase into the sewerage system in Switzerland seem to exist.

In Switzerland, it becomes obvious that measures taken in waste management in past (restrictions of disposal on landfills, ban for sewage sludge as fertilizer in agriculture, separate e-waste recycling concept, etc.) and actions by industry (stewardship programmes) have had a positive impact on the emission situation. However, there are still problems to be addressed in near future (e.g. emissions of HBCD from insulation panels during use and construction operations, diffuse emissions from unintended fires, export of used products, recycling processes and infrastructure). The situation is different in the EU, as in many countries sewage sludge is still used in agriculture and burnable waste containing BFRs is dumped on landfills.

Acknowledgements
The project was funded by the Swiss National Science Foundation (Project FABRO, 4050-111389, National Research Programme 50).

References

Anonymous. 1999. Brominated Flame Retardants: Substance Flow Analysis and Assessment of Alternatives, Danish Environmental Protection Agency, Copenhagen.

Klatt M. 2004. The Third International Workshop on Brominated Flame Retardants, Toronto, Canada.

Kohler M, Zennegg M, Hartmann PC, Sturm M, Gujer E, Schmid P, Gerecke AC, Heeb NV, Kohler HP, Giger W. 2005. 15th annual meeting of SETAC Europe, Lille, France.

Kohler M, Schmid P, Hartmann PC, Sturm M, Heeb NV, Zennegg M, Gerecke AC, Gujer E, Kohler HP, Giger W. 2006. 16th annual meeting of SETAC Europe, The Hague, The Netherlands.

Morf LS, Taverna R, Daxbeck H, Smutny R. 2003. Selected polybrominated flame retardants, PBDEs and TBBPA, Substance flow analysis. Environmental Series No. 338, Swiss Agency for the Environment, Forests and Landscape, Berne.

Morf LS, Tremp J, Gloor R, Huber Y, Stengele M, Zennegg M. 2005. Environ Sci Technol 39:8691.

Sakai SI, Hirai Y, Aizawa H, Ota S, Muroishi Y. 2006. J Mater Cycles Waste Manag 56-62.

Tokai, A., H. Yamaguchi, K. Tsunemi, Y. Yonezawa, M. Tominaga and J. Nakanishi. 2004. SRA Annual Meeting, Palm Springs, California